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An evaluation of equivalent grades of sintered carbide inserts

Bruce R. Rauhe
Lehigh University

AN EVALUATION OF EQUIVALENT GRADES OF SINTERED CARBIDE INSERTS

by

Bruce Robert Rauhe

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George E. Kane
Professor in Charge

Head of the Department
of Industrial Engineering

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Tungsten Alloy Mfg. Co., Inc.
Valeron Corporation
Vascoloy Ramet Corporation
Walmet Corporation
Wendt-Sonis Company

My wife deserves credit for her moral encouragement and understanding during the period of research and preparation of this paper.

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Bruce Robert Rauhe

Abstract

The "Carbide Manufacturer's Grade Recommendation" chart is one of several mediums used to aid in the selection of grades of sintered carbide inserts. This chart, which is published by many carbide manufacturers, has several shortcomings: (1) The industry designation code areas are poorly defined, (2) the range of materials covered by these areas is excessively wide, and (3) there is no assurance of equivalent performance between the grades of carbide recommended for the same industry code.

This paper includes the results of a test which statistically proves the lack of equivalent performance between the grades of carbide recommended for industry code C-6. Also included is a suggested method for recoding the current industry codes which will better describe quantitatively the various cutting situations for which carbide grades are recommended. The new code is based on a detailed breakdown of material, depth of cut, feed, and cutting speed. There is, in addition, a suggested method for assuring at least a minimum level of performance through the use of minimum standards of performance for the industry. The minimum standards of performance are determined by testing, and only those grades which exceed this standard are approved by the industry for inclusion in a recommendation chart.

I - Introduction

Users of carbide tools are faced with a large selection of work materials, cutting conditions, and grades of carbide inserts. This set of variables represents an almost infinite number of possible combinations from which the tool engineer must select the one best combination for any particular application. The work material and design specifications are stipulated by the design engineer or by the customer, so it becomes the responsibility of the tool engineer to determine the most economical cutting conditions and tooling necessary to produce the product.

There is a wealth of literature concerning the proper coolant to use[1], the most economical tool life[2], and the optimum tool geometry[3] for various metal removal situations. The Carboloy Division of the General Electric Company has published an excellent pamphlet titled HI-E (HI-Efficiency) concerning the economics of metal removal; calculation of the most economical tool life for maximum production or least cost per piece. The factors which determine optimum tool geometry are many, and suggested geometries are published in numerous catalogs and handbooks. The Machining Development Service of Carboloy has published a pamphlet[4] which correlates the factors affecting surface finish, a major specification criteria which the tool engineer must consider, in charts and graphs to enable the user to determine what speeds, feeds, and tool shapes he must use to obtain a desired surface finish. Experimentation to better understand the cutting process is still going on, and more quantitative results are being published to enable the user to better determine his optimum cutting onditions and tooling.

The <u>Tool Engineer's Handbook</u> gives broad classifications as to the compositions and typical uses of cemented tungsten carbide tools and dies. These classifications cover a wide range of properties and applications. General statements have also been made concerning the addition of tantulum, titanium, and columbium to the basic tungsten carbide to improve crater, edge wear, and heat resistance. The broadness and generalness of the classifications and statements makes it difficult to match exact compositions with specific applications, even if it were possible to find out the compositions of all of the various grades of carbide produced. Variations in the methods of manufacture, grain size, and purity make the composition by itself, of the various grades, a dubious standard by which to judge performance. The variations in physical properties (Fig. 1) between grades of carbide recommended for the same application seem to indicate that there is uncertainty as to what properties are best for a given application. A study of the grades of carbide from one company indicated that the same values of hardness and transverse rupture strength were described for the carbide grades specified for cutting both ferrous and nonferrous materials, and to different conditions of feed, depth of cut, speed, and work material hardness. Generally the user must judge by trial and error; if the tool fails by cratering, use a harder grade with more TaC; if the tool fails by cracking or chipping, use a softer grade; if the tool fails by excessive edge wear, use a harder grade of carbide. There is no exact formula as yet.

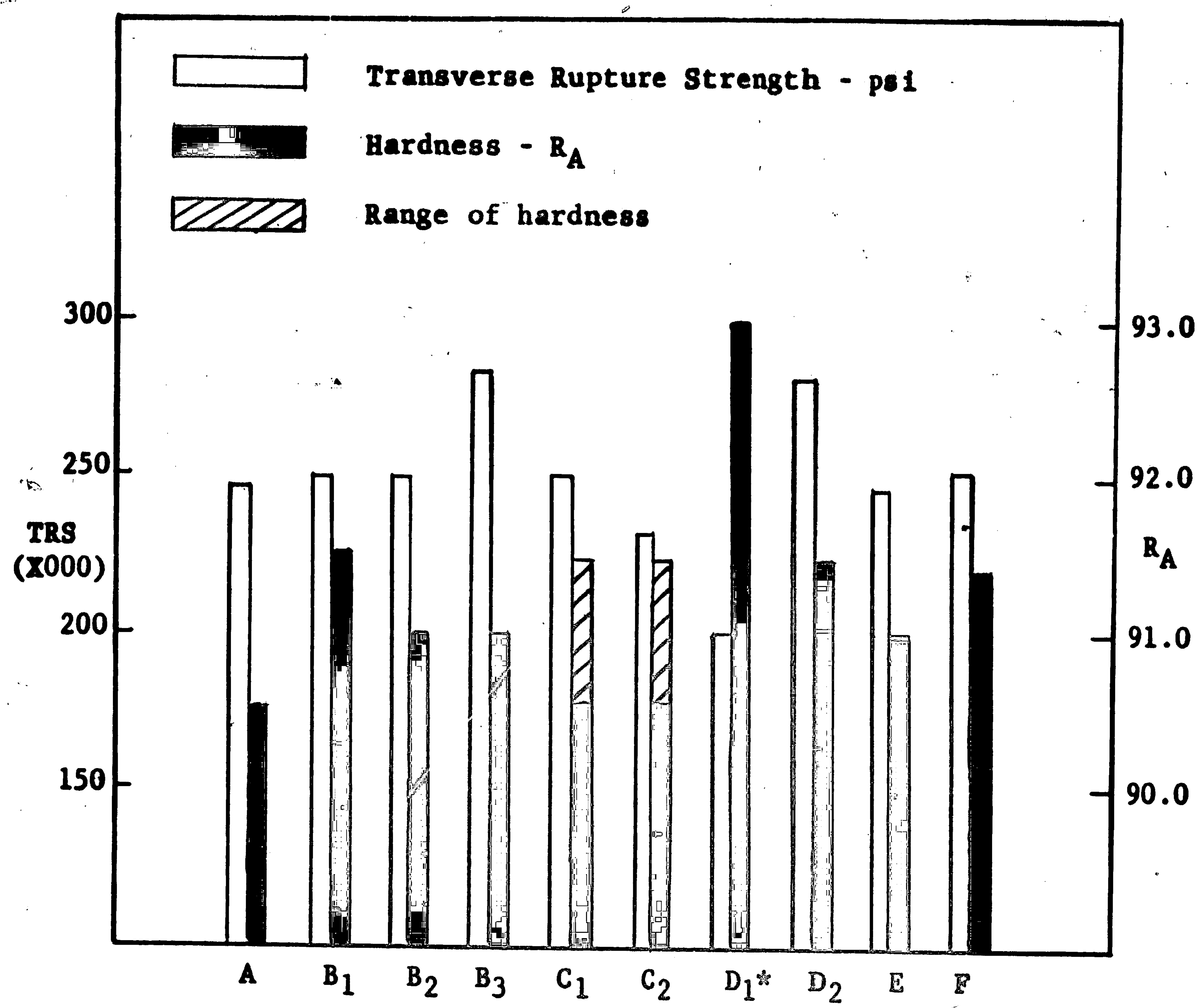


Figure 1: Hardness and Transverse Rupture Strength values for grades of carbide inserts recommended for industry code C-6 on the "Carbide Manufacturer's Grade Recommendation" charts. *Grade D_1 was selected from the manufacturer's catalog for the experiment conditions described later, although this grade was not shown on a "Grade Recommendation" chart as applicable to code C-6.

There still remains the selection of the tool material. Let us assume that carbide is the tool material that has been selected. The tool engineer has available to him several courses of action to enable him to arrive at a decision regarding what or which grade to use: He may (1) select a grade from a manufacturer's catalog, (2) receive assistance from a manufacturer's field representative, (3) request several grades of carbide from several manufacturers and test their performance, or (4) select a grade from the "Carbide Manufacturer's Grade Recommendation" chart. This last course of action by itself is not necessarily valid, but it will be explained later where this method is used.

Course of Action 1: Several producers of carbide inserts publish charts in their catalogs that specify which of their grades to use for specific cutting conditions of work material, work hardness, feed, and depth of cut. Also included in some of these charts is a recommended cutting speed for the particular combination of cutting conditions and grade of carbide. Those producers who do not publish such charts do, however, describe in general terms those applications for which their grades of carbide are best suited. The detailed charts are the result of intensive experimentation by the producers, and, it can be assumed, represent the best applications of their products. What is missing from those charts which include recommended cutting speeds is the tool life for which these speeds were computed. This aspect of grade selection will be discussed in Section VI, Economic Considerations.

Course of Action 2: Although the grade of carbide selected with the assistance of a manufacturer's field representative would probably be the same as that selected from the catalog alone, there are additional benefits to be derived from this course of action; the experience of the representative with metal cutting problems. In those cases where the grade application is described in general terms, it is almost a necessity to contact the manufacturer or his representative in order to be sure of the right selection.

Note that both of these courses of action are dependent on a single manufacturer. What is the assurance that the grade selected, albeit it is the best from that manufacturer for that application, is the best from among all the grades produced? Or perform as well as any produced?

Course of Action 3: To obtain the necessary assurance that the grade selected is the best it is necessary to test and compare. The amount of testing would of course depend on the facilities, time, and money available. The extremes of this course of action would be no testing, and the testing of all possible combinations of grades and cutting conditions. The lower limit of no testing might prove to be uneconomical, and the upper limit of complete testing is not feasible. Therefore, a compromise is suggested for those companies whose tooling costs are high, and which have the facilities, time, and money available. Determine the work materials and cutting conditions which are used most often, request inserts from several carbide producers (the grades to be selected by the producers for the work materials and cutting conditions specified), and compare the results under actual working conditions. It is doubtful that the same manufacturer will produce the best grades for all of the work material and cutting condition combinations. The test criteria to be tool life, where tool life is the time until the tool no longer performs its function, i.e., complete failure, failure to hold demensional tolerance, or unacceptable surface finish.

Even the testing of grades from a single manufacturer could be accomplished if there was available some standard of performance against which a comparison could be made. Granted that a test of this type, if a standard were available, might distinguish only if the grade tested gave satisfactory or unsatisfactory performance. This type of test against prepared standards of performance could apply to those companies without adequate facilities, time, and money for extensive experimentation.

But there has been no literature published in this country on what level of performance you should expect from carbide tools for a given set of cutting conditions. There are no standards available for the user. Some experimentation has been done in Switzerland[5] on ISO* grades K10 and K20 for cast iron, P10 and P20 for continuous cutting of steel, and P30 and P40 for interrupted cutting of steel[6]. The statistical methods for evaluating the results of comparison tests are available. The means for determining standards of performance are therefore available.

Course of Action 4: In an effort to simplify for the user the selection of grades of carbide, the carbide producers have prepared a "Carbide Manufacturer's Grade Recommendation" chart. A portion of a typical chart is reproduced in Figure 2. This chart is reproduced in nearly every manufacturer's catalog, and indicates which carbide grade is recommended for certain application areas (cutting conditions). An examination of the chart will reveal differences in chemical composition as well as in physical properties (Fig. 1). The chart has the purpose of being a guide, a starting point, and it is clearly stated at the bottom of each chart that "it is not intended as a grade comparison chart". However, there is an inherent implication in the

*International Organization for Standardization chart that the grades are comparable, for each manufacturer is in effect stating that his carbide grade will do the job (and, it is assumed, do it best) for the application area indicated. By comparable it is meant that the performance of the various grades within a particular application area are comparable; i.e., equivalent performance.

Industry Code	Adamas	Carboloy	Carmet	Firth Loach	Talide	Valenite	Vascoloy Ramet
							VR-77
C-5	434	370	CA-51	FT-3	S88X	VC-5	AW
							EE
C-50	950	370	CA-610	FT-41	S-88	VC-125	VR-75
			CA-720	FT-5		VC-5	
C-6	D	78B	CA-609	FT-4	S-90	VC-125	EM
						VC-6	
C-7	C	78	CA-608	FT-6	S-92	VC-7	VR-73
							E
C-70	548	350	CA-606	FT-61	S92X	VC-7	VR-73
				FT-62			
C-8	CC	330	CA-605	FT-7	S-94	VC-8	EH

Figure 2: Carbide Manufacturer's Grade Recommendation Chart. No attempt has been made to edit the grades shown on this chart. This is only a portion of the chart from which these grades were reproduced; there are other manufacturers, and other industry codes.

When is the chart used? Government agencies have been instructed to solicit bids from three or more manufacturers when purchasing major items. These instructions are contained in the Armed Services Procurement Regulations (ASPR), and in the Air Force Procurement Instructions (AFPI). The purpose of this instruction is to minimize the dependency of procurement agencies on a single source of supply, and to place these agencies in a better competitive position. In actual practice a carbide grade is specified by the methods or tool engineer, and it is left to the purchasing department to request bids from the manufacturer of the grade of carbide specified and from two other manufacturers with equivalent grades. The selection of these other grades and manufacturers is quite often the responsibility of individuals with little or no knowledge of metal cutting. The selection has been made by reference to the "Grade Recommendation" chart. In one government agency which uses a large amount of carbide inserts - a recent investigation determined that this was indeed the procedure used - nearly $186,000 of unusable carbide inserts were found to be in inventory. This is not so mute testimony that there are shortcomings associated with such use of the chart.

There are three major shortcomings in the "Grade Recommendation" chart: (1) The application areas are ill-defined by the industry coding (Fig. 3), (2) the individual application areas cover an excessively wide range of materials with their associated variance in machinability, and (3) there is no assurance of comparable performance of the grades recommended for any application.

CHIP REMOVAL APPLICATIONS:

C-5	Roughing cuts - steel
C-50	Rough cuts and heavy feeds - steel
C-6	General purpose - steel
C-7	Finishing cut and heavy feed - steel
C-70	Finishing cut and fine feed - steel
C-8	Precision boring - steel

Figure 3: Standard Industrial Grade Classification. These definitions were taken from one manufacturer's catalog. Those in other catalogs were basically the same.

There is most certainly more than one type of steel, and that these different types of steel range in ease of machining from B-1112, with a machinability rating of 1.00, to M-252 or M-308 with a machinability rating of 0.05. These machinability ratings were taken from the General Electric HI-E Pocket Calculator. These steels require carbide tools with varying properties, and yet the "Grade Recommendation" chart makes no distinction between types of steel.

What is the quantitative description of a roughing cut as distinct from a general purpose or finishing cut? There is no agreement in the industry on this question. When asked, knowledgiable men have answered anywhere from 0.015 to 0.100 inches for a finishing cut, and in some catalogs 3/8 inch depth is considered as a finishing cut. It, of course, depends on a factor other than only feed and depth of cut. It depends on the surface finish desired.

Is the "Grade Recommendation" chart then usable? The purpose of this paper is to test the validity of the chart, determine whether or not such a chart is practical, and investigate quantitative methods for determining performance standards for carbide inserts.

II - Objectives

The "Carbide Manufacturer's Grade Recommendation" chart has been published in an effort to aid the users of carbide products in choosing suitable carbide grades for various fabricating applications. The purpose of this paper is to (1) test by statistical methods a part of the "Grade Recommendation" chart, (2) discuss the practical application of this chart, and (3) investigate quantitative methods for determining performance standards of carbide inserts.

To these ends an experiment was designed to test the validity of the "Grade Recommendation" chart by comparing statistically the performance of the grades of carbide inserts recommended for a specific application area. First, the experiment conditions will be described, then the statistical methods which were used to determine the significance of the data will be covered, and finally the practical implications of using the "Grade Recommendation" chart will be discussed in light of the experimental results.

The last sections of this paper are devoted to a discussion of some of the economic considerations when selecting carbide inserts, and methods for determining performance standards for carbide inserts.

This paper was written from the viewpoint of the user, and not from the viewpoint of the manufacturer. Therefore, the problems of manufacture are not the concern of this paper, but only the problem of performance assurance for the user.

III - Experiment Conditions

The purpose of this experiment was to test the validity of the "Carbide Manufacturer's Grade Recommendation" chart. Can you expect comparable or equivalent performance if you use the chart as a means for selecting grades of carbide from several manufacturers for the same application? Therefore, the design of the experiment was such that the grades of carbide inserts were already specified on the chart, and there remained the selection of the particular application area, work material, representative cutting conditions, and test criteria.

Because of the lack of definition of the application areas and industry codes in the "Grade Recommendation" chart, certain assumptions had to be made as to what would be representative of the area and code selected. The broad application area of CHIP REMOVAL which pertains to ferrous materials includes the industry designation codes C-5 through C-8. AISI 4340 was selected as a typical steel which would apply to this area. The bar stock used had a constant hardness throughout of 321 Bhn, and varied in diameter from 6 1/2 to 3 inches during the continuous cutting, and from 6 7/8 to 6 1/2 inches during the interrupted cutting.

The area designated by industry code C-6, General Purpose, was selected, although any other industry code pertaining to ferrous materials could have been used. Again there was the problem of definition: What is a "General Purpose" cut? Reference was made to the ASME bulletin <u>Life Tests for Single-point Tools of Sintered Carbide</u>

(ASA B5.34-1956), and from among the six suggested sizes of cuts that one was chosen which was considered as representative of a General Purpose cutting situation; i.e., 1/8 inch depth of cut and 0.020 inch feed. Initially the next lower size of cut had been selected, but several manufacturers took exception to these conditions. They considered the lower size of cut, 0.100 inch depth and 0.0125 inch feed, as more applicable to area C-7 or C-70, Finishing.

The General Electric Machinability Computer was used to determine the cutting speed necessary to give a wear land of approximately 0.015 inches in one to two minutes. For continuous cutting this was 300 SFPM. These values of wear and time were chosen to reduce the time for the tests although the inserts could have been used longer. This speed is not necessarily the cutting speed recommended by the manufacturers for their particular grades of inserts, nor do they specify on what tool life they base their recommended speeds. Since it was necessary to maintain a constant cutting condition for the test, these recommended speeds were not considered.

It was stated in the descriptions of many of the grades of carbide used that they could be used in moderate interrupted cutting situations. No statement concerning the type of cutting situation - continuous or interrupted - is made in the description of the industry codes used in the "Grade Recommendation" chart. Therefore, the same grades were applied to an interrupted cutting situation except that the feed and depth of cut were decreased to reduce the severity of the test, and to maintain the wear land in the vicinity of 0.015 to 0.025 inches.

The amount of wear land was selected as the measure of performance for which the various grades of carbide were to be compared. The amount of flank land wear is one of the accepted measures of performance used by experimentors.

Of the 17 producers of carbide inserts who were contacted, 10 contributed inserts of the grades requested for the experiment. The grades requested for the experiment were determined from the "Grade Recommendation" charts published by the individual manufacturers, except where a chart was not published. In this case a composite of all of the charts was made and the grade specified on a majority of the charts was used (see Appendix A). No one chart could be used since the charts were not consistent between manufacturers as to the grades recommended for area C-6.

The industrial coding for the size of inserts used was SNU-433 (SQT-163U3) for continuous cutting, and SNG-433 (SQT-163P3H) for interrupted cutting. It was felt that a utility ground, unhoned insert was adequate for continuous cutting, although honing might have improved the performance of the inserts. A precision ground, honed insert was specified for the interrupted cutting to minimize the effects of thermal cracks. The size used agreed with that recommended by some manufacturers for the cutting conditions in the experiment.

Three inserts of each grade were tested for each cutting condition, one cut on each for two minutes (continuous) or one minute (interrupted), to identify the variation between the individual inserts of a manufacturer. No attempt was made to identify the variability within an insert.

The wear land was measured with a microscope, and the average of the wear lands on the three inserts was used as the performance value of that grade of insert.

A summary of the cutting conditions is shown in figure 4, and the raw data, average value, and range are reproduced in Appendices B and C. Appendix B refers to those grades specifically recommended for area C-6 on the "Grade Recommendation" charts, and Appendix C refers to those grades submitted by the manufacturers but not recommended on the charts for area C-6.

Material: AISI 4340 321 Bhn
Heat #104H392 Bethlehem Steel Company

Composition:	C	M	P	S	Si	Ni	Cr	M
	.43	.80	.025	.020	.27	1.72	.83	.25

Machine: LeBond 16" HD Engine Lathe 20 HP

	Continuous	Interrupted*
Depth of cut	0.0125"	0.050"
Feed	0.0204"	0.0051"
SFPM	300	400
Time	2 min.	1 min.
Condition	Dry	Dry
Insert	SNU-433 Unhoned	SNG-433 Honed
Tool Holder	Carboloy SBTR-16	Carboloy SBTR-16

* 5/8" milled slot to give interrupted cut.

Figure 4: Experiment Conditions

IV - Analysis of Experimental Data

The raw data was grouped into two classifications for both the continuous and interrupted cutting; that data generated by the grades recommended in the "Grade Recommendation" charts for industry code C-6, and that data generated by all of the grades submitted by the manufacturers regardless of their applicability to area C-6.

The hypothesis to be tested was that the performances of the grades recommended for area C-6 were the same, and only chance variations were the cause of any differences in performance. The first statistical tests applied were the Analysis of Variance and F-tests.* These tests were applied to both of the classifications described above. The Analysis of Variance was run on a GE 225 computer (program number D3.005 - Lehigh University), and the results are shown in Appendix D. The variance ratios (F statistic) were then compared to a table of the probability points of the variance ratio (F distribution). The variance ratios from the Analysis of Variance are:

	Continuous	Interrupted
Area C-6	21.7	7.4
All grades	21.8	7.85

The statistical interpretation is that there is a highly significant difference between the grades of carbide inserts submitted for this experiment. The hypothesis that the performance of the different grades

* These tests and charts can be found described in any standard textbook on statistics.

was the same would be rejected at the 99% level of confidence. This does not indicate which grades are significantly different.

Control charts were made to identify those grades which deviated significantly from the mean level of performance. Since the machine used was the same for all of the runs, and the cutting conditions were held constant, the variability in performance beyond that within the grades would be from the differences between the grades. Although an R chart is not shown, the range limits were calculated to determine if the variability within the grades was in control and statistically reliable. The ranges were calculated as follows:

<u>Continuous Cutting</u>

Upper Limit $= \bar{R} + 3d_3/d_2 \cdot \bar{R} = 0.0093''$

Lower Limit $= 0$

<u>Interrupted Cutting</u>

Upper Limit $= 0.0298''$

Lower Limit $= 0$

All of the data was in control except where noted in Appendices B and C, and if not in control the data was not used in the computations for the $\bar{X}$ charts.

The $\bar{X}$ charts were then constructed using the average range ($\bar{R}$) to estimate sigma, and the limits set at three sigmas (99.73% level of confidence). This level may be considered as high since two sigmas (95%) is usually judged to be highly significant. The limits were calculated using the average range ($\bar{R}$) and the standard A_2 (n=3) multiplier.

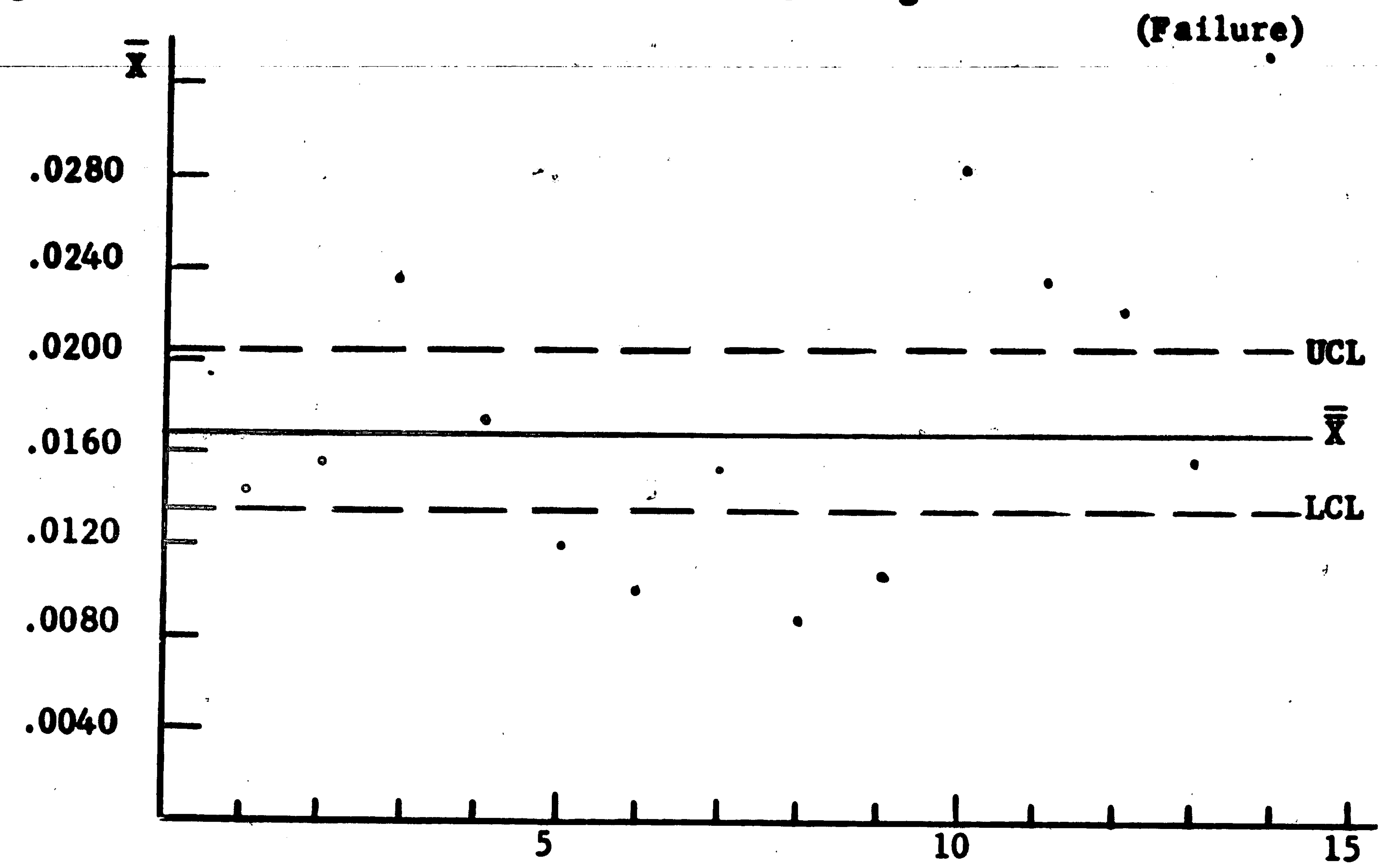
The control charts for continuous and interrupted cutting are shown in figures 5 and 6 respectively. Since the ranges remained within limits for the grades not applicable to area C-6 a new $\bar{\bar{X}}$ and limits were not calculated; the difference in the grand averages between those grades applicable to area C-6 and all of the grades tested is relatively small - less than one sigma.

Those grades above the upper limit would be considered as unsuitable for the work material and cutting conditions used in the experiment, while those below the lower limit would be considered as over-designed for the work material and cutting conditions used in the experiment. Note again that the "Grade Recommendation" chart does not indicate specifically the type of steel to which industry code C-6 applies, so that the significance of this particular experiment relating to the relative performances of the grades tested can only be assessed against the work material and cutting conditions used. The relative performances of the grades could change as the work material and cutting conditions were varied within the indistinct limits of what would be described as a "General Purpose" application.

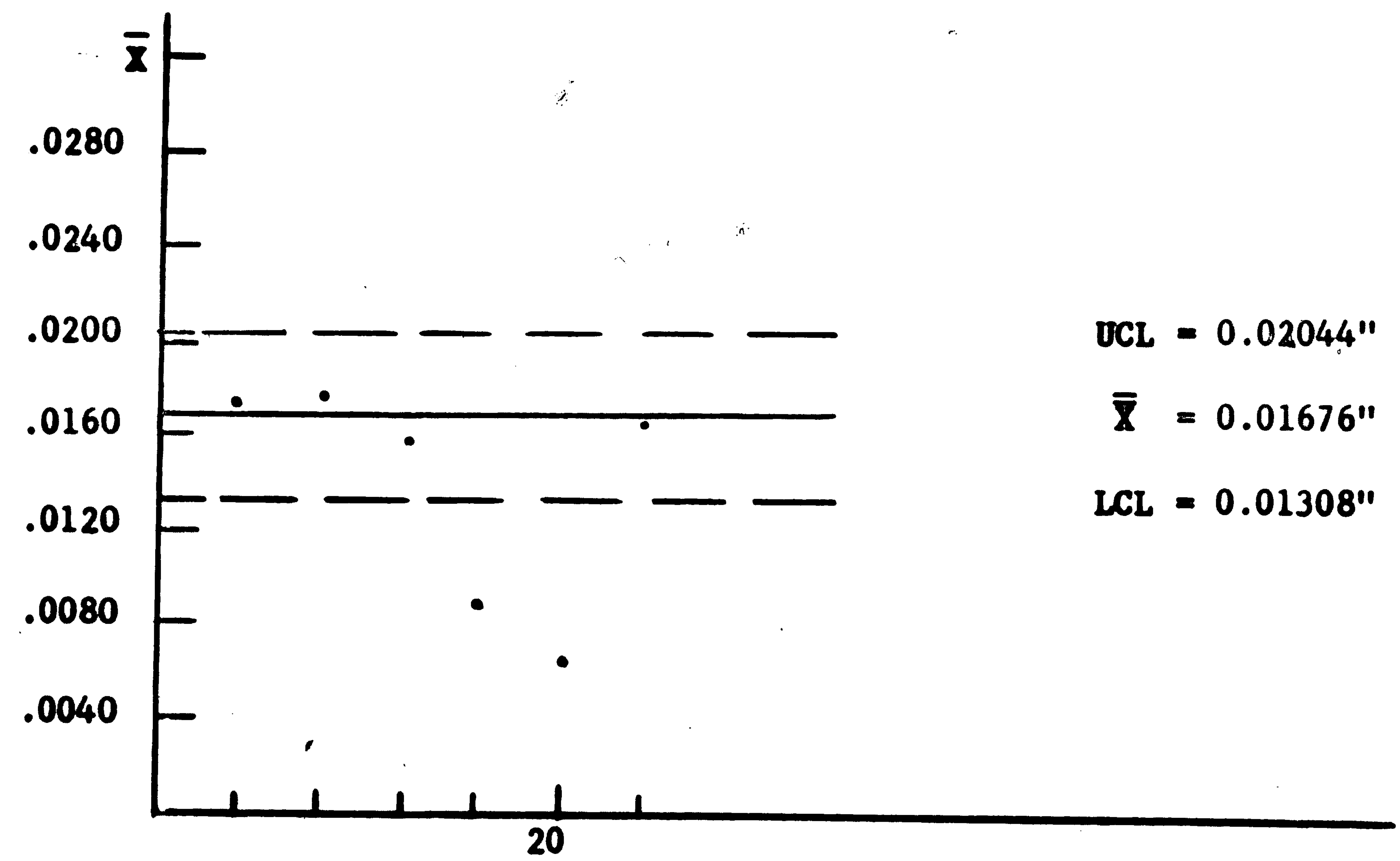
No attempt was made to determine the exact distribution of the raw data since the distribution of the sample averages approaches a normal distribution regardless of the parent population.[7]

It should be noted that the measurement of the wear land on the inserts used for the interrupted cut was made to include any chipping or fracture that may have occurred. This is not unusual, since the type of failure associated with interrupted cutting situations is generally fracture or chipping rather than edge wear. From an investigation of the control charts it is apparent that those grades judged unsuitable for continuous cutting were not necessarily unsuitable for interrupted cutting when compared to other grades. Conversely, those grades with superior performance for continuous cutting were not necessarily superior for interrupted cutting.

Figure 5: Control Charts for Continuous Cutting.

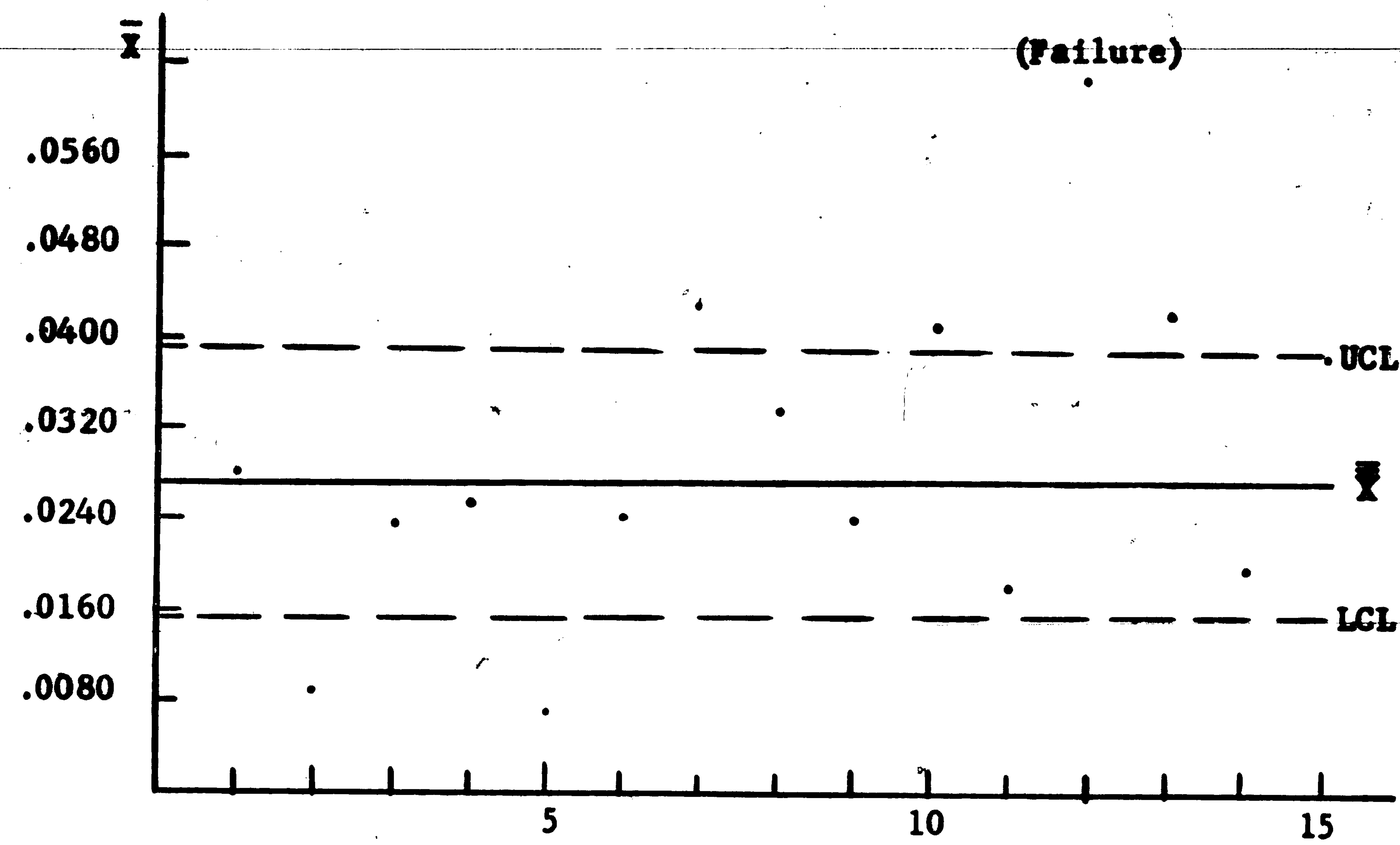


Grade Sample Code Number
Application Area C-6

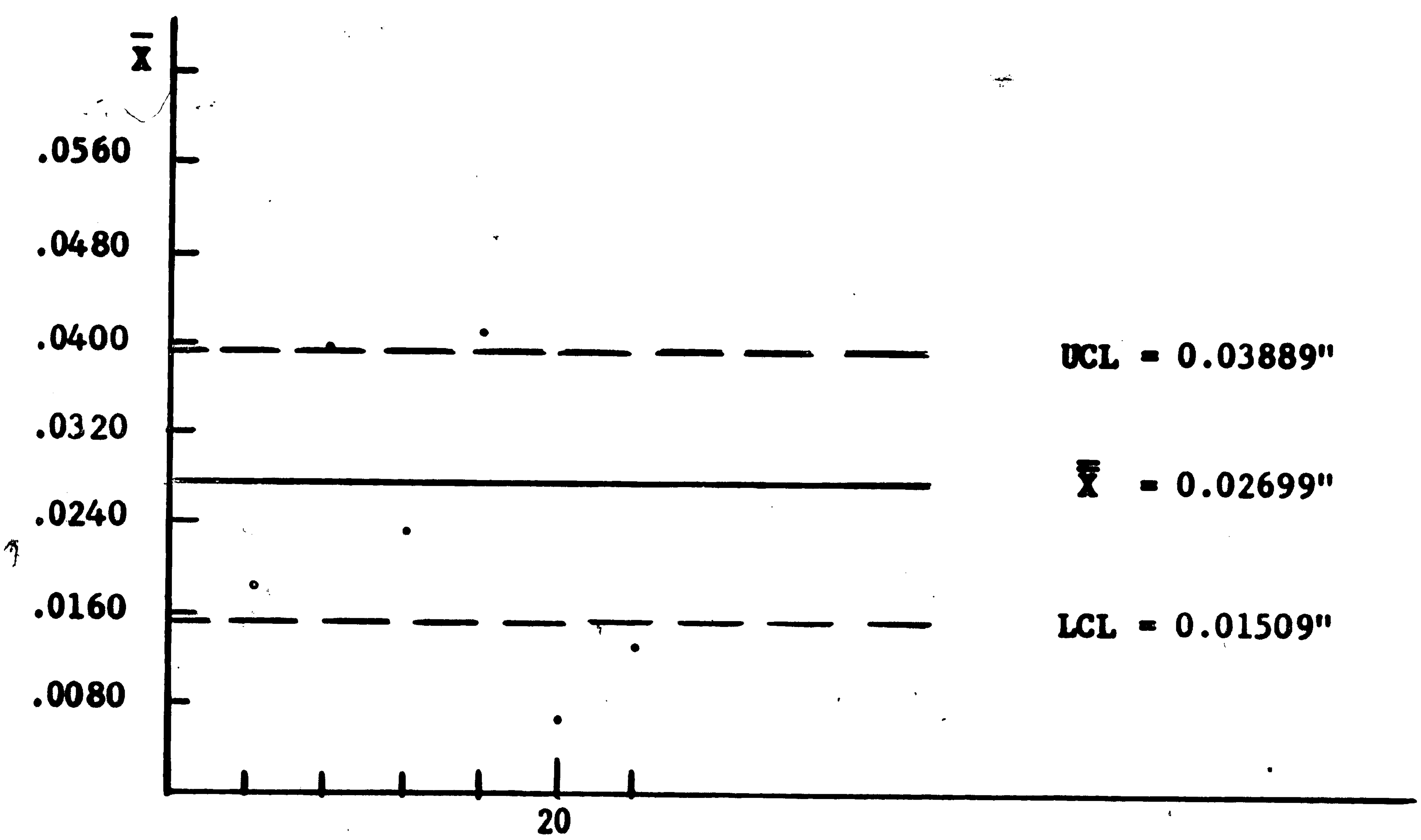


Grade Sample Code Number
Non-Applicable Grades

Figure 6: Control Charts for Interrupted Cutting.



Grade Sample Code Number
Application Area C-6



Grade Sample Code Number
Non-Applicable Grades

V - Discussion of "Carbide Manufacturer's Grade Recommendation" Charts

This discussion of the "Grade Recommendation" charts will be limited primarily to the industry code areas C-5 through C-8 which are applicable to the machining of steel. Refer again to the comments made earlier concerning the shortcomings of the chart; lack of area definition, an excessively wide range of materials covered, and the lack of assurance of comparable performance between the grades of carbide recommended for application within these areas.

Discussions with men experienced in the field of metal cutting have indicated their lack of agreement on any quantitative definition of what constitutes a finishing, general purpose, or roughing cut. If it can be accepted that a finishing cut is "that combination of depth of cut, feed, and speed which will give a desired surface finish", then it can be seen that a quantitative, all inclusive definition is not required. The surface finish must be specified first, and then the cutting conditions selected to meet this requirement. The difference in the cutting conditions necessary to produce a 32rms or 500rms surface finish is enormous. The term "finishing cut" implies that some specified surface finish must be obtained, but it certainly does not imply by itself a distinct set of cutting conditions or range of cutting conditions.

Similarly, it can be argued that the terms "general purpose" and "roughing" do not in themselves imply any distinct, quantitative range of cutting conditions except as might be defined by individuals based on their own experience.

The second shortcoming of the charts is that the type of work material covered by industry codes C-5 through C-8 refers to steel or steel alloys, with no more definition than that. If a " ? " number of men were asked to define the term steel, or steel alloy, by a single type, you would probably get " ? " different answers. Accepting the fact that there is an appreciable difference between the machining characteristics of (say) Astroloy and B-1112 steels, or even between a 200 Bhn and 321 Bhn 4000 series steel, then it must also be agreed that the terms steel and steel alloy cover an extremely wide range of machining situations. The terms do not adequately describe the material being cut.

It is not sufficient, therefore, to define the cutting application in such nebulous terms as "steel" and "finishing", or any other qualitative combination of terms. The cutting situation must be defined in terms of the specific work material, depth of cut, feed, and speed in order that a valid selection of tool material may be made.

The work material classification presently used in the "Grade Recommendation" charts can be expanded into categories of common machining characteristics, differentiated by hardness or machinability ratings. The validity of using either hardness or machinability ratings may be open to question, but these were mentioned since they are presently used by some manufacturers as parameters for cutting applications.

Surface finish is a function of cutting speed, tool geometry, feed, and work material.[4] Assume that the cutting speed has already been calculated for the most economical tool life (see Section VI - Economic

Considerations), the tool geometry determined, and the surface finish and work material specified. The remaining cutting conditions of depth of cut and feed are then selected to give the specified surface finish. The surface finish, work material, and most economical tool life are the basic factors (neglect the effect of cutting fluid for this discussion) which determine, or eventually lead to, a complete definition of the cutting situation. At this point a choice of carbide grade can be made, but only after the entire cutting situation has been quantitatively defined. If interrupted cutting is also a part of the cutting situation, then this too would have to be considered since the description of many grades of carbide includes a statement of their shock resistant qualities.

The third shortcoming of the "Grade Recommendation" chart concerning the lack of assurance of comparable performance between grades has been proven within the limits of the experiment and statistical analysis previously described.

It is therefore apparent that the present form of the "Grade Recommendation" chart is inadequate as a means for aiding the selection of grades of carbide. Reference is made to the use of the chart (course of action 4) mentioned in Section I. Expanding the chart to cover every work material and cutting condition would be infeasible, and would make the chart unwieldy. And yet, it is nearly impossible to expand the chart much more (unless the size of the print is reduced) and still keep it simple and on one page. But cutting situations are not simple for there are too many factors involved. Some manufacturers have the solution right now - the Grade Selection chart which they publish in their catalog in addition to the "Grade Recommendation" chart.

Work Material	Hardness		FINISHING			
			Up to 1/16 Depth Under .005 Feed		1/16 - 3/16 Depth .005 - .015 Feed	
			Speed	Grade	Speed	Grade
	150		1500-2000		1000-1600	
	200		1200-1800		900-1200	X
Free Machining	250	24	800-1500	X	700-1000	X
Plain Carbon	300	32	650-850	X	500-750	
Steels, Plain	350	37	550-700		400-600	X
Carbon Steels,	400	43	450-600	X	350-550	X
Alloy Steels,	425	45	400-550	X	300-500	
and 400 & 500	450	47	375-500		250-450	X
Series Stainless	475	49	330-400	X	200-300	X
Steels	500	51	300-375	X	175-250	
	525	53	250-375		125-200	X
	550	55	200-275		100-150	X

Figure 7: A Portion of a Grade Selection Chart. The X's indicate the location of the grades recommended by the manufacturer.

These Grade Selection charts (Fig. 7) define explicitly the work material and cutting conditions. A particular grade of carbide is then recommended for narrow ranges of work material and cutting conditions. The only objections to these charts are the use of the qualitative terms "finishing" and "roughing" (using the same argument as before), the failure of the manufacturers to mention the tool life on which the recommended cutting speeds are based, and the failure to distinguish between continuous and interrupted cutting. The first objection would be removed by not using the terms "finishing" or "roughing" on the chart, for this would be determined by the user based on his own surface finish requirements. The second objection would be removed by including the tool life used. This point will be discussed further in Section VII,

Standardization. The third objection would be removed by using a separate chart for interrupted cutting.

Note that the Grade Selection chart is separated into two main areas (only a portion of the complete chart was reproduced in figure 7): (1) Free machining steels, plain carbon steels, et cetera, and (2) the other major types of steels and non-ferrous materials. The first area covers steels and steel alloys which are probably the most used.

Not all manufacturers publish a Grade Selection chart. It is suggested that this chart be used as the basis for a new industry designation code which will define specific cutting situations (Fig.8). Any letters, numbers, or combination of letters and numbers may be used - this is of minor importance. What is important is the fact that a quantitative description would exist for most cutting situations.

Work Material	Hardness		Up to 1/16 Depth Under .005 Feed		1/16 - 3/16 Depth .005 - .015 Feed	
			Speed	Grade	Speed	Grade
	150		1500-2000		1000-1600	
	200		1200-1800		900-1200	
Free Machining	250	24	800-1500	A1C	700-1000	B1C
Plain Carbon	300	32	650-850		500-750	
Steels, Plain	350	37	550-700		400-600	
Carbon Steels,	400	43	450-600		350-550	B2C
Alloy Steels,	425	45	400-550	A2C	300-500	
and 400 & 500	450	47	375-500		250-450	
Series Stainless	475	49	330-400		200-300	B3C
Steels	500	51	300-375		175-250	
	525	53	250-375	A3C	125-200	
	550	55	200-275		100-150	B4C

Figure 8: A Portion of a Grade Selection Chart With a Suggested Method for Recoding the Present Industry Designation Code.

With this chart and coding system the manufacturers could still recommend grades of carbide as they now do in the "Grade Recommendation" chart, but they would be recommending grades for a specific cutting situation. In the interest of simplicity, only that portion of the chart applicable to the more common steels need be coded, but this would leave a large number of work materials uncovered.

This suggested solution resolves the problems of lack of definition and material coverage, but it does nothing to resolve the problem of assuring comparable performance between grades recommended for the same cutting situation. This problem is the subject of Section VII, Standardization.

VI - Economic Considerations

It is not the intent of this paper to discuss the correctness or derivation of formulas used to calculate the most economical tool life. However, certain considerations should be mentioned when comparing the economics of using one grade instead of another.

Briefly, the factors which enter into determining the cost per piece associated with using various types and grades of tooling are:[8]

(1) The original cost of the tool.

(2) The cost of regrinding the tool, if necessary.

(3) Tool changing costs.

(4) Labor and overhead costs.

(5) Non-machining costs such as loading, traverse time, etc.

At first it would seem that the longer the tool life then the lower will be the cost per piece. This is not true. It is reasonable to expect that the slower the cutting speed (within limits) the longer will be the tool life. Also, for the same depth of cut and feed rate, a decrease in cutting speed will result in a decrease in the amount of metal removed. However, the time per piece will also increase until you reach a point where the savings resulting from not having to change and regrind (if necessary) the tool will be offset by increased machining costs. Therefore, there is a point where the cost per piece will be least.

Similarly, if maximum production is the goal, there is a point where increasing cutting speed will increase the time per piece because of the need for more frequent changing of the tools.

The Carboloy Division of the General Electric Company covers this concept in their pamphlet HI-E, which was mentioned earlier. The formulas which they use contain the term n, while other formulas which are used to determine cutting speed use n and also a term C. The term n refers to the slope of the tool-life line, and the term C is the intercept of this line with the cutting speed axis which are obtained from the familiar tool-life vs. cutting speed graphs.

Assume that the primary consideration is to determine the optimum cutting speed to give the most economical tool life. By economical is meant least cost per piece or maximum production, and by tool life is meant the time until the tool no longer performs its function - total failure, or unacceptable surface finish or demensional tolerance. From tool-life vs. cutting speed graphs for the particular work material, cutting conditions, and tooling used the cutting speed can be determined given the desired tool life. Unless the various grades of carbide recommended for these conditions are comparable, then the slope and the intercept of the tool-life line will vary, and the cutting speeds for each grade will differ. The grades of carbide recommended for the same cutting situation are not the same, as the results of the experiment have shown. Therefore, one grade will do the job faster than another; i.e., a faster cutting speed for the same tool life.

The last item to consider is tool cost. It is safe to assume that given identical products the one which costs less is the one to buy, unless there are other factors involved, e.g., dependability of delivery, good will, et cetera. But what if the cost is the same and the products are not the same? This is indicated from the results of the experiment. Then it is necessary to calculate the tool-life and cutting speeds from the formulas available for various values of n and C. If, for the same tool cost, one grade can be used at a faster cutting speed for the same tool life, then it is the one to buy. Investigation of the costs available for the inserts submitted indicates that premium grades as a group do not necessarily out-perform non-premium grades. The difference in published base price is generally around 14 cents. In this case it will be necessary to calculate and compare the most economical tool life and cutting speed for each grade.

Therefore, identical insert prices and assumed comparable performance are not valid factors to use when selecting grades of carbide for tooling. To make a valid decision of which grade of carbide to use there must be the assurance of comparable performance. This can be accomplished by industry standardization, unless the user has the time, money, and facilities to test the individual grades of carbide available.

VII - Standardization

To continue the discussion from Section V: There still remains the problem of assurance of comparable performance between the grades of carbide recommended for the same cutting situation. There was also a reference to tool life, the discussion of which was partially deferred until this time. These points will be covered, but first it is necessary to develope the conditions under which a comparison of grades can be made, or that standardization is possible.

That a logical comparison can be made - in the context of this paper - implies that the basis for comparison is the same for all of the items of interest; i.e., the cutting conditions are the same for each grade of carbide. These cutting conditions are specified in the Grade Selection chart which was proposed in Section V. There is also the implication that the items selected for comparison, the grades of carbide, are <u>intended</u> to be compared against each other. This intent would be evidenced by a user selecting and testing several grades of carbide from several manufacturers, or, in this case, by manufacturers recommending grades of carbide for specific cutting situations as shown on the Grade Selection chart. If there is no intent or medium for comparison, then there can be no standardization. The medium of the proposed Grade Selection chart will be the basis for this discussion, for the chart has a universal application to all users, rather than an application to a single user. Therfore, the bases for a comparison are present; common cutting conditions, and the intent for comparison, both through the medium of the Grade Selection chart.

To compare the grades of carbide it is necessary to specify the cutting situation or test conditions. Since the cutting situation is defined on the Grade Selection chart, the last item to determine is the time period for which the comparison will be made, assuming that performance will be the criteria. This can be done in two ways: (1) Use the same cutting situation (material, depth of cut, feed, and speed) shown on the chart, and then use any time desired for the test, or (2) leave the cutting speed off the chart, and specify the test parameters by means of a standard test procedure, e.g., test procedures recommended and published by the Cemented Carbide Producer's Association. It is assumed in method (1) that the speeds shown on the Grade Selection chart are based on some predetermined tool life and value of n, and that these speeds are common to all of the grades of carbide. The first method is perhaps the best, for the inclusion of recommended speeds on the chart, with their associated tool life, could serve as a guide for users.

It is suggested that a Grade Selection pamphlet be published giving the new industry coding, and Grade Selection charts for both continuous and interrupted cutting (Appendix E). In order for a manufacturer to have his grades shown in the Grade Selection Pamphlet, those grades would have to be capable of exceeding a specified minimum level of performance. Referring to the experiment conditions and statistical analysis techniques described in this paper, the same methods and criteria of performance could be used. The minimum level of performance could be set at plus two sigmas (or any point agreed on by the manufacturers) on an $\overline{X}$ chart. The variation between the inserts of any single grade would have to fall within the limits of an R chart to insure statistical reliability of the generated data. A testing procedure of this type would assure the user of, at least, a minimum level of performance for any grade he might select.

Nothing has been said concerning a lower limit (exceptional performance). This condition of over-design is the problem of the individual manufacturer. There is no evidence to be found in the experiment performed for this paper that the same grade of carbide would necessarily perform outside of the lower limit for the entire range of applications for which it was recommended. Nor is there any evidence that those grades with sub-standard performance would remain sub-standard over the entire range of applications for which they were recommended. From an inspection of the proposed Grade Selection chart (Fig. 8), it would seem that for a given depth of cut and feed the range of hardness and speed for which a grade is recommended is narrow enough so that the position of a grade relative to the other grades tested would not change appreciably within this range. This may or may not be true, but would have to be checked by further experimentation.

As a suggestion, the test conditions could be set at the midpoints of the feed and depth of cut ranges, and at selected hardness or speed values. For example: 1/8 inch depth of cut, 0.010 inch feed, and at 250, 350, 450, and 500 Bhn hardness levels, with the speeds corresponding to these hardness values - 850, 500, 350, and 215 SFPM. These are only suggested values. The actual parameters of the tests would be determined by the manufacturers.

There is no attempt made to identify the best grade for any particular cutting situation, for this is the prerogative of the individual user. Grades which perform below the minimum standard of performance are just not shown on the chart or in the pamphlet. The important point is that the user is assured of relatively camparable performance above a certain minimum level. This minimum level being based on the expected performance of all the grades produced and recommended for a specific cutting situation.

Those manufacturers with grades of carbide which perform below standard, or those with new grades, should be allowed to submit these grades for testing at any time they feel these grades will perform satisfactorily. The grades already above standard must also be retested periodically to insure that a constant quality has been maintained, and to revise the standard limit if needed. The pamphlet containing the Grade Selection charts for the participating manufacturers should be republished or revised at predetermined intervals.

This proposal for standardization will require a central, unbiased organization to monitor the testing program, and to publish the Grade Selection pamphlet. The expense of this program would, of course, be paid by the participating manufacturers, although part of the expense might be recovered from the users through subscriptions.

Although this paper has been primarily concerned with throw-away or brazed inserts, there is no apparent reason why a similar proposal cannot be applied to the other industry code areas. There is an obvious need for standardization as long as there are any "Grade Selection" or "Grade Recommendation" charts published which show the grades of carbide recommended by various manufacturers for specific cutting situations. A minimum standard of performance would act as an incentive to manufacturers to produce a high quality product.

Perhaps the need for a Grade Selection chart is not so apparent. As long as the Government retains its present purchasing policy these charts are needed, for without a reliable chart, and the subsequent poor performance of some grades of carbide, government agencies will feel the need to perform their own testing. The results of these tests will be in the form of Qualified Products Lists which will, in fact, identify the best grades and manufacturers. The manufacturers of carbide products can preclude this from happening if they will standardize and police the carbide industry themselves.

In addition, the presence of a minimum standard of performance and the identification of approved grades would be an excellent selling point for the manufacturers of a quality product. The precedent has been set in other industries; e.g., the Good Housekeeping Seal of Approval, AAA approved motels, et cetera.

There is a need for a reliable comparison chart, and for standardization within the carbide industry.

VIII - Conclusions

(1) The "Carbide Manufacturer's Grade Recommendation" chart does not give assurance of equivalent performance between the grades recommended for a given industry code area. There are statistical differences in the performance of carbide grades recommended for industry code C-6 for both continuous and interrupted cutting.

(2) The "Grade Recommendation" chart is not adequately defined in terms of work material or cutting conditions.

(3) The "Grade Recommendation" chart is not adequately defined in terms of continuous or interrupted cutting.

(4) The present industry designation code must be revised to provide for a more quantitative description of the cutting situation.

(5) It is necessary that a minimum standard of performance be calculated for the described cutting situations, and that above standard grades of carbide be identified.

IX - Recommendations

It is recommended that:

(1) The present "Carbide Manufacturer's Grade Recommendation" chart be revised as a Grade Selection pamphlet (Appendix E).

(2) The industry designation code be revised to better define specific cutting situations (Appendix E).

(3) An organization be formed or designated to publish the Grade Selection pamphlet, and to monitor or perform a testing program.

(4) A testing program be started, and testing procedures be designed based on the cutting situations described in the Grade Selection charts to determine minimum standards of performance for carbide inserts.

(5) All manufacturers of carbide inserts become members of this organization, and underwrite the publishing and testing expenses of the organization.

Appendix A

Composite Chart of Carbide Grades Submitted

Manufacturers	Industry Codes C-5	C-6	C-7
Adamas	434	D	548
Besly-Welles		B-102	
Carboloy	370	78B	
Coromant	S-4 S-6	S-2	
Firthomet		FT-5	FT-62
Tungsten-Alloy		10T	
Valenite		VC-125 VC-6	
Vascoloy-Ramet		VR-75 HR WM	
Walmet		WA-6	
Wendt-Sonis		CY-5 CY-16 CY-17	

Note: These grades were arranged under these industrial codes based on the manufacturer's individual recommendations except where the manufacturer made no such recommendation. In that case, the code recommended by a majority of the other manufacturers was used.

Appendix B

Raw Data for Application Area C-6

Condition: Continuous Cutting.

Grade Code	Run 1	Run 2	Run 3	($\bar{X}$) Average	(R) Range
1	.0131	.0173	.0131	.0145	.0042
2	.0153	.0169	.0148	.0157	.0021
3	.0283	.0222	.0207	.0237	.0076
4	.0195	.0157	.0171	.0174	.0038
5	.0121	.0118	.0122	.0120	.0004
6	.0105	.0096	.0098	.0100	.0009
7	.0156	.0159	.0132	.0149	.0027
8	.0112	.0048	.0098	.0086	.0064
9	.0121	.0103	.0091	.0105	.0030
10	.0287	.0291	.0284	.0287	.0007
11	.0216	.0261	.0242	.0240	.0045
12	.0222	.0179	.0266	.0222	.0087
13	.0163	.0166	.0142	.0157	.0024
14	Failure	.0510	.0535	*	*

($\bar{\bar{X}}$) Grand Average .01676

($\bar{R}$) Average Range .0036

* Further runs of this grade resulted in complete failure, so this grade was not considered in the calculations.

Condition: Interrupted Cutting.

Grade Code	Run 1	Run 2	Run 3	($\bar{X}$) Average	(R) Range
1	.0245	.0327	.0255	.0276	.0082
2	.0055	.0063	.0140	.0086	.0085
3	.0209	.0222	.0286	.0239	.0077
4	.0251	.0247	.0252	.0250	.0005
5	.0074	.0064	.0071	.0070	.0010
6	.0145	.0254	.0330	.0243	.0185
7	.0530	.0502	.0276	.0436	.0254
8	.0269	.0350	.0400	.0340	.0131
9	.0199	.0217	.0303	.0240	.0104
10	.0449	.0416	.0375	.0413	.0074
11	.0166	.0255	.0119	.0180	.0089
12	.0668	.0527	Failure	*	*
13	.0253	.0548	.0490	.0430	.0295
14	.0200	.0104	.0267	.0190	.0163
15	.0430	.0362	.0369	.0387	.0068
			($\bar{\bar{X}}$) Grand Average	.02699	
			($\bar{R}$) Average Range		.0116

* Further runs of this grade resulted in complete failure, so this grade was not considered in the calculations.

Appendix C

Raw Data for Grades Not in Application Area C-6

Condition: Continuous Cutting.

Grade Code	Run 1	Run 2	Run 3	($\bar{X}$) Average	(R) Range
16	.0200	.0154	.0161	.0172	.0046
17	.0152	.0200	.0173	.0175	.0048
18	.0146	.0158	.0171	.0158	.0025
19	.0076	.0091	.0099	.0089	.0023
20	.0064	.0054	.0078	.0065	.0024
21	.0142	.0177	.0169	.0163	.0035

Condition: Interrupted Cutting.

Grade Code	Run 1	Run 2	Run 3	($\bar{X}$) Average	(R) Range
16	.0179	.0225	.0144	.0183	.0081
17	.0320	.0420	.0436	.0392	.0116
18	.0182	.0212	.0286	.0227	.0104
19	.0535	.0228	.0462	.0408	.0307*
20	.0045	.0087	.0050	.0061	.0042
21	.0156	.0107	.0139	.0134	.0049

* Although the range for this grade was slightly out of limits, the values of wear were used in the calculations for the Analysis of Variance and F-test.

Appendix D

Analysis of Variance for Factoral Designs

Condition: Continuous Cutting.

(1) Data applicable to area C-6:

Effect	DOF	Sum of Squares	Mean Squares
Between Grades	12	0.13784533-02	0.11487111-03
Within Grades	26	0.13779332-03	0.52997432-05
Total	38	0.15162466-02	
Grand Mean		0.16766667-01	

Variance Ratio = 21.7

(2) Composite data:

Effect	DOF	Sum of Squares	Mean Squares
Between Grades	18	0.18316526-02	0.10175848-03
Within Grades	38	0.17714669-03	0.46617551-05
Total	56	0.20087993-02	
Grand Mean		0.15796491-01	

Variance Ratio = 21.8

Condition: Interrupted Cutting.

(1) Data applicable to area C-6:

Effect	DOF	Sum of Squares	Mean Squares
Between Grades	13	o.55148430-02	0.42421869-03
Within Grades	28	0.16024466-02	0.57230236-04
Total	41	0.71172896-02	
Grand Mean		0.26997619-01	

Variance Ratio = 7.4

(2) Composite data:

Effect	DOF	Sum of Squares	Mean Squares
Between Grades	19	0.86201025-02	0.45368961-03
Within Grades	40	0.23091534-02	0.57728835-04
Total	59	0.10929256-01	
Grand Mean		0.25920000-01	

Variance Ratio = 7.85

Appendix E

Suggested Grade Selection Pamphlet

(1) Outline for the Grade Selection Pamphlet:

Page 1	Industry code
Page 2	Manufacturer recommendations for continuous cutting.
Page 3	Manufacturer recommendations for interrupted cutting.

(2) Suggested industry codes:

Code*	Depth	Feed	Hardness
A1C	Under 1/16"	Under .005"	150-350
A2C	"	"	350-475
A3C	"	"	475-550
B1C	1/16-3/16"	.005-.015"	150-300
B2C	"	"	300-425
B3C	"	"	425-500
B4C	"	"	500-550
C1C	1/8-3/8"	.010-.030"	150-300
C2C	"	"	300-425
C3C	"	"	425-500
C4C	"	"	500-550
D1C	1/4-1/2"	.020-.050"	150-300
D2C	"	"	300-425
D3C	"	"	425-500
D4C	"	"	500-550
E1C	3/8-3/4"	.030-.070"	150-350
E2C	"	"	350-475
E3C	"	"	475-550
F1C	Over 5/8"	.040-.100"	150-350
F2C	"	"	350-475
F3C	"	"	475-550

* The last letter designates the type of cutting; continuous (C) or interrupted (I).

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Vita

Name:	Bruce Robert Rauhe
Home:	1940 Alamanda Drive Keystone Point North Miami, Florida
Birthdate:	29 October 1929
Birthplace:	Rochester, New York
Parents:	Mrs. Bernard V. McElwee
Education:	Staunton Military Academy Staunton, Virginia BS Industrial Engineering Lehigh University 1953
Professional Experience:	
	Advanced Planning Section Fractional Horsepower Motor Division General Electric Company DeKalb, Illinois Jul 53 - Oct 53
Present Occupation:	Captain, United States Air Force

Coding Sheet

Code Group	Grade
1	S-2
2	FT-5
3	78B
4	VC-125
5	VC-6
6	B-102
7	D
8	VR-75
9	HR
10	WA-6
11	CY-17
12	CY-5
13	CY-16
14	10T
15	WM
16	S-4
17	S-6
18	370
19	FT-62
20	548
21	434